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Fire Resistance Testing of CLT Floor/Ceiling Assemblies to Establish Contribution of Gypsum Protection

Indicative testing conducted following the test methodology described in ASTM E119: Standard test methods for fire tests of building and construction materials

Conducted For:

American Wood Council
222 Catoctin Circle SE, Suite 201
Leesburg, VA 20175

WFCi Report #17091r1

Test Date: October 31, November 1 & 3, 2017

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ACCREDITED
Testing Laboratory TL-180

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INTRODUCTION

This report describes the fire resistance testing of three load-bearing floor/ceiling cross-laminated timber (CLT) assemblies until failure. Test assemblies were subjected to a standard time-temperature exposure as described in ASTM E119, *Standard test methods for fire tests of building and construction materials*, for the American Wood Council of Leesburg, VA.

The CLT panels were fabricated by a CLT manufacturer and shipped to WFCi for testing. Two CLT panel sections were shipped for each assembly, joined together at WFCi, and tested on the horizontal furnace. Various layers of gypsum were applied to the underside of the CLT to provide additional protection. The overall floor/ceiling assembly area was 13'11"×18'2" with clear span dimensions of 13'4'×17'7'. The objective of these tests was to isolate and quantify the contribution of various amounts of gypsum protection to the overall fire resistance of CLT floor/ceiling assembly. In an effort to ensure that each test could be carried out to a consistent comparison point at which the structural failure was imminent attempts were made to minimize burn-through at the CLT spline.

SUMMARY OF TEST METHOD

Testing was performed using a horizontal fire resistance test furnace employing the fire endurance conditions and standard time-temperature curve described in ASTM E119. Temperature measurements were taken inside the natural gas furnace using 9 thermocouples (TC_F) connected to a computerized data acquisition system. TC_F locations were symmetrically disposed and distributed to show the temperature near (within 12") the exposed face of the test assembly. At periods when the fuel load contribution of the specimen made it difficult to control the temperature within the furnace by gas flow regulation alone, water was introduced in the furnace to better control the temperature to align to the standard time-temperature curve.

For comparative purposes between the results of the tests within the series, the time-to-failure of each test was taken as the time at which a consistent mid-point deflection of at least 12" was reached. Based on the results of Test 3, which exhibited a structural failure approximately 1 min after the test was terminated upon reaching a mid-point deflection of 12", this 12" deflection was considered to be a consistent comparison reference point at which structural failure was imminent for this particular loading configuration and CLT grade/thickness.

The standard criteria for floor/ceiling assemblies are typically judged according to ASTM E119 are also reported below for information and are reported. However the ultimate test termination was judged by the mid-point deflection as described above, provided that the assembly was still safe to continue.

- Assembly will have sustained the applied load for the indicated time (2-hr +, in this instance) without passage of flame or gases hot enough to ignite cotton waste
- Transmission of heat through the assembly will not have risen the temperature on its unexposed side more than 139°C (average) above its initial temperature, or if a temperature higher than 30% (181°C) of the specified limit occurs at any one point (single-point) on the unexposed side of the assembly.

SAMPLE DESCRIPTION

Each floor/ceiling assembly was 13'11"×18'2" and rested upon one 1½"×3½" bearing plates around the perimeter, resulting in clear span demensions of 13'4'×17'7'. The strong axis of each CLT panel was oriented parallel to the 17'7" span direction. The materials and method of construction is described below. Layers of Kaowool insulation were inserted and packed along the assembly bottom, insulating the unexposed perimeter of the assembly at the top edges of the horizontal furnace opening.

Cross-Laminated Timber Panels

Each assembly was constructed with 5-ply CLT layers, each ply consisting of 1⅜"×5½" boards aligned and joined together with adhesive. Successive layers were laid up in the perpendicular direction, each layer joined together with adhesive. Lumber and adhesive together gave the overall depth of approximately 6⅞". The same CLT product was used for each test (SmartLam, Spruce-pine-fir [SPF], polyurethane adhesive [PUR]). Additional information regarding the CLT panels used in each test is detailed below:

- **Test 1**: "Fire Test 4", Moisture content: ~14%. Mass: 3884.7 lb (combined mass both panels).
- **Test 2**: "Fire Test 3", Moisture content: ~14%. Mass: 3756.2 lb (combined mass both panels).
- **Test 3**: "Fire Test 2", Moisture content: ~14%. Mass: 3820.6 lb (combined mass both panels).

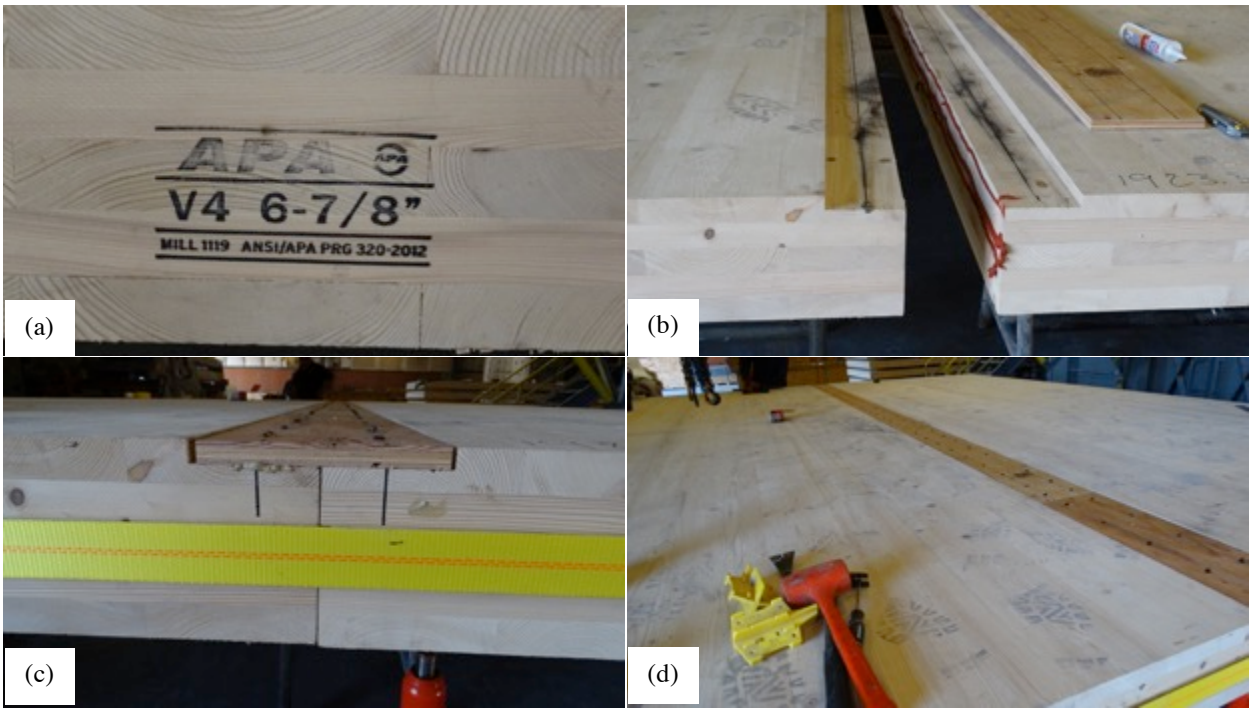

Figure 1. Representative CLT panels showing (a) cross-section and identification, (b) joint, (c) joined assembly, and (d) complete assembly.

Two identical panels (6'11½"×18'2") were sent for each test, each with a 4" spline (¾" deep) cutout for the two panels to be joined together (Figure 2). The outer perimeter had a 1½" vertical board fastened with screws to each panel to give the 6'11½" length. A 7¾" wide (¾" deep) plywood spline strip was fastened into the spline cutout with 4" (TimberLOK) wood screws at 6" on center spacing, 2" from centerline. A continuous bead of subfloor adhesive (PL 400) was applied under the plywood strip at the fastener locations. To minimize the likelihood that the tests would need to be terminated prior to reaching structural failure as a result of potential burn-through at the plywood spline, a 10" wide layer of ceramic insulation (Kaowool) was placed on top of the plywood spline. Additionally, continuous beads of fire barrier sealant (3M CP 25WB 4 hr) were applied to sides of the CLT joint at the upper three (3) ply interfaces for Test 1. For subsequent tests (Tests 2 & 3), the sealant was applied to all five (5) ply interfaces. Below the floor/ceiling assembly perimeter was placed two nominal 2×4 wood baseplates, giving a clear span of 13'4"×17'7".

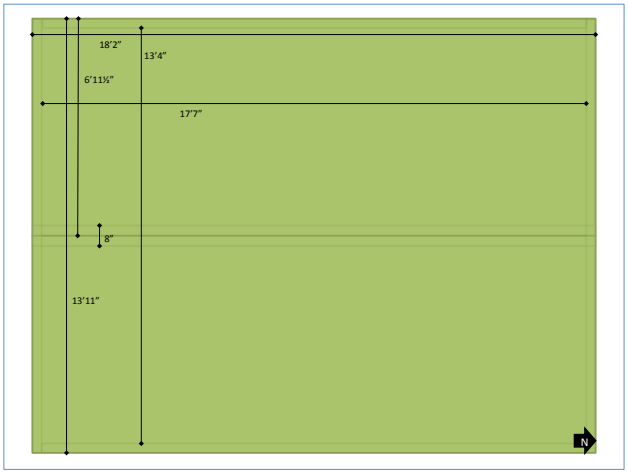

Figure 2. Floor/ceiling schematic showing CLT panels.

Gypsum Ceiling

Layers of ⅝" Type X gypsum (FIRECODE® X [UL TYPE SCX], USG 240 09/27/17, R1319-240 TYPE SCX) were applied to the ceiling (underside) of the joined CLT panels, depending on the amount of protection provided. The mass of the gypsum was 2.24 lb/ft^2, and the face layer joints were taped (2") and covered with two layers of dry mix joint compound. The exposed screw heads were also covered with two layers of compound. The layers for each test are described as follows with schematics shown below:

- **Test 1**: 1 layer of gypsum. Fastened with 1⅝" (#6 Type S) screws at 12" on center in each direction with perimeter screws 1½" from the edge (see Figure 3).
- **Test 2**: Control. No gypsum layers.
- **Test 3**: 3 layers of gypsum. Base layer fastened with 1⅝" (#6 Type S) screws at 12" on center in each direction with perimeter screws 1½" from the edge. Middle layer fastened with 2¼" (#6 Type S) screws at 12" on center in each direction with perimeter screws 1½" from the edge. Face layer fastened with 3" (#8 Type S) screws at 12" on center in each direction with perimeter screws 1½" from the edge. Screws were staggered 4" between each successive layer (see Figure 4).

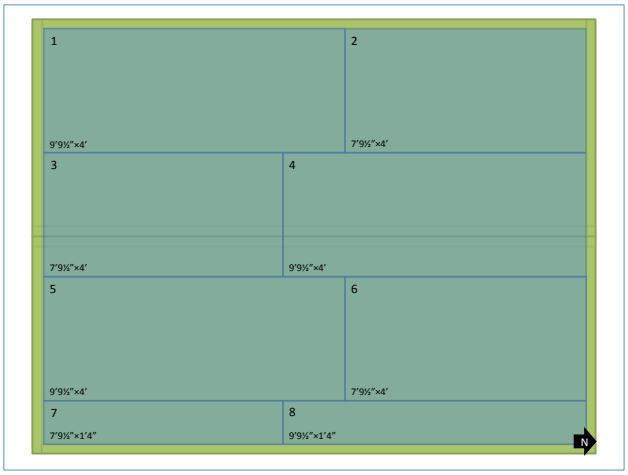

Figure 3. Gypsum layout for Test 1.

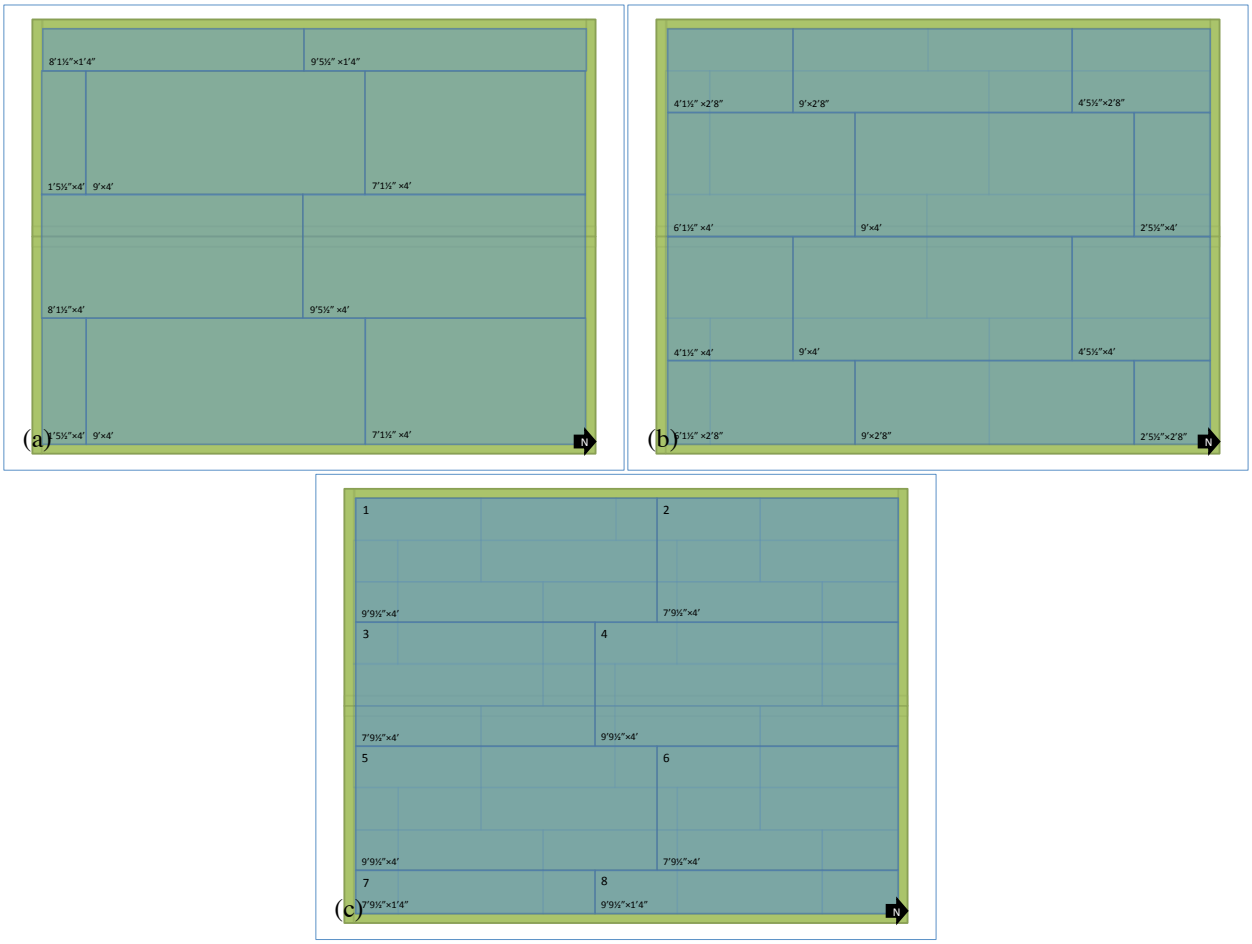

Figure 4. Gypsum layout for Test 3 showing (a) base layer, (b) middle layer, and (c) face layer.

Sample Thermocouples

Sample thermocouples (TC_S) were used to better describe temperature behavior for the load-bearing assembly. TC_S locations are described below and in Figure 5:

- Finish (TC_S1-5): Positioned between base layer of gypsum and bottom of CLT panel (Tests 1 & 3 only).
- Unexposed (TC_S6-14): Placed on top of the CLT panels. Each was covered with a 6”×6” dry ceramic fiber pad.
- Base/Middle Gypsum Interface (TC_S15-17): Placed between base and middle layers of gypsum (Test 3 only).
- Middle/Face Gypsum Interface (TC_S18-20): Placed between middle and face layers of gypsum (Test 3 only).

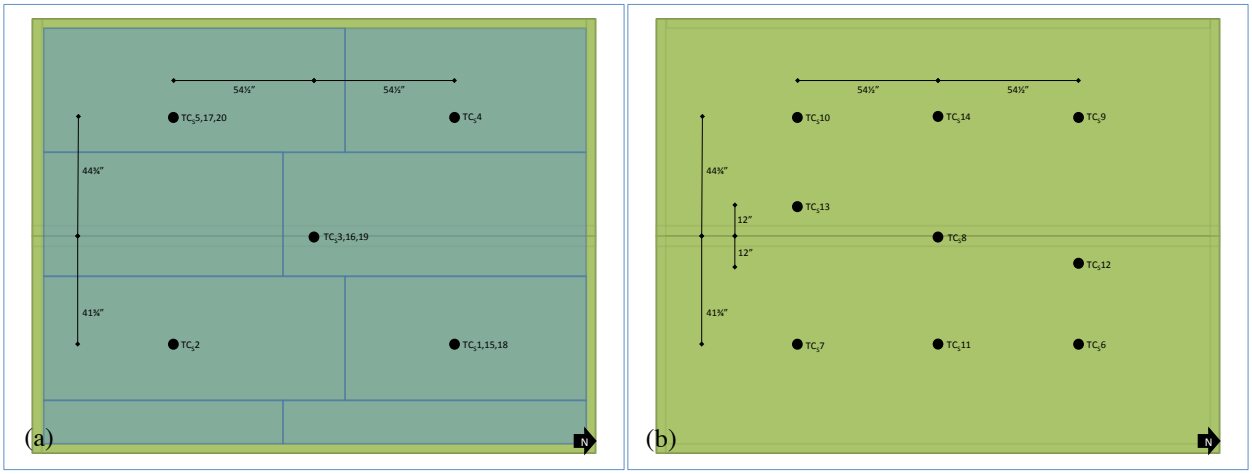

Figure 5. Thermocouple (TC_S) placement on assembly showing (a) finish and gypsum interface layer temperature and (b) unexposed temperature.

Individual groups were averaged together to give a general temperature rise through the assembly, and are reported in each test below.

Loading and Deflection

A superimposed load was applied to provide a uniformly distributed live load of 60.0 lb_f/ft^2, or a combined live and dead load of 77.64 lb_f/ft^2, 74.98 lb_f/ft^2, 81.61 lb_f/ft^2, for Tests 1-3, respectively. The loading to the assembly was accomplished by 24 weighted barrels (632 lb/barrel or 15,169 lb total), each placed upon two 36”, nominal 4×4 wood bunks and equally spaced across the floor surface as shown in Figure 6.

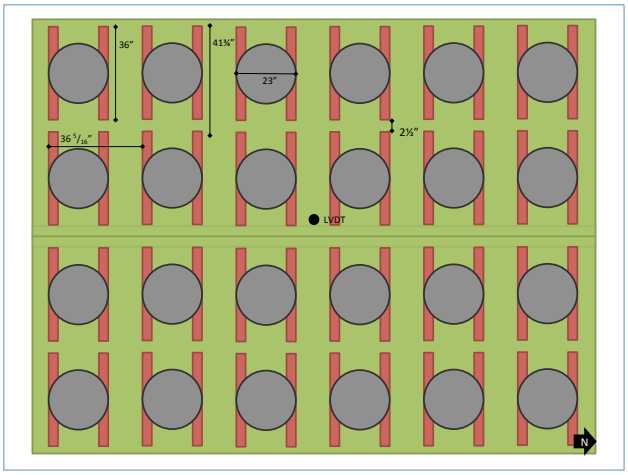

Figure 6. Loading configuration showing barrels placed on loaded bunks and LVDT location.

The deflection of the floor assembly was measured with one linear voltage displacement transducer (LVDT) located near the geometric center of the assembly (Figure 6), just west of the spline joint.

TEST RESULTS

Testing of the assemblies took place on October 31, November 1 & 3, 2016. Upon initiation of the test, the furnace and sample temperatures (TC_F, TC_S) and LVDT were continuously monitored at 1 Hz until test termination. These temperature data are presented below. Additional data and photographs of the assembly during construction and before, during, and after the test are also provided below and in Appendix A – Additional Figures. Jason Smart (AWC) and Naveen Punati (USG) witnessed the tests.

Test 1: One Layer Gypsum

Test Date & Time: 10/31/17, 11:10 PM

Furnace: Large-scale horizontal exposure furnace – full-scale E119

Laboratory Conditions: 12°C, 55% RH

Table 1. Test 1 observations for floor/ceiling test.

Test Time (mm:ss)		**Event**
00:00		Start test – close doors to furnace
01:50		Paper ignition of gypsum
12:00		Fallen compound from butt joint
17:00		Fallen compound from tapered joint
21:13		TC_S1-5 > 151°C – average finish rating temperature threshold reached
23:00		Field crack in gypsum at CLT panel joint
26:00		Slight flames at joints

28:30		Increasing flames at joints
33:00		Increasing flames – approximately 1' to 1½'
49:00		Board #3 peeling away at crack
53:30		Board #2 peeling away at butt joint
58:00		Small section of gypsum fell from board #2
1:02:00		Large section of gypsum fell from board #3
1:03:00		Large section of gypsum fell from board #4
1:06:00		More sections fallen – start periodic introduction of water into furnace for temperature control
1:28:00		Continued water application into furnace
1:30:00		Embers from CLT layer fallen to furnace floor
2:08:00		Some of 2nd layer ply falling
2:18:00		Approximately 2¾" deflection
2:28:00		Popping from assembly
2:30:30		Approximately 4.2" deflection
2:38:00		Continued popping
2:40:30		Approximately 6" deflection
2:47:30		Approximately 7" deflection
2:52:00		Approximately 7.8" deflection
2:57:00		Approximately 9" deflection
3:03:00		Approximately 10½" deflection – $TC_S11 > 193°C$ – single-point unexposed rating temperature threshold reached
3:05:00		Flames on unexposed side when water applied – localized positive pressure
3:10:00		Sustained flames on unexposed side at joint
3:11:00		Terminate test – deflection beyond 12" – sustained flames along joint

The test was terminated at 191 m 0 s, after the deflection was beyond 12" (189 m 42 s) and structural failure of the assembly was imminent. Also, sustained flames were observed on the unexposed surface near the joint at 190 m 0 s. Unsustained flames were observed at 185 min, but this was due to localized pressure increase from the water application to the furnace. Thus this assembly fulfilled the requirement of maintaining the applied load without passage of flame for 3 hr 10 m.

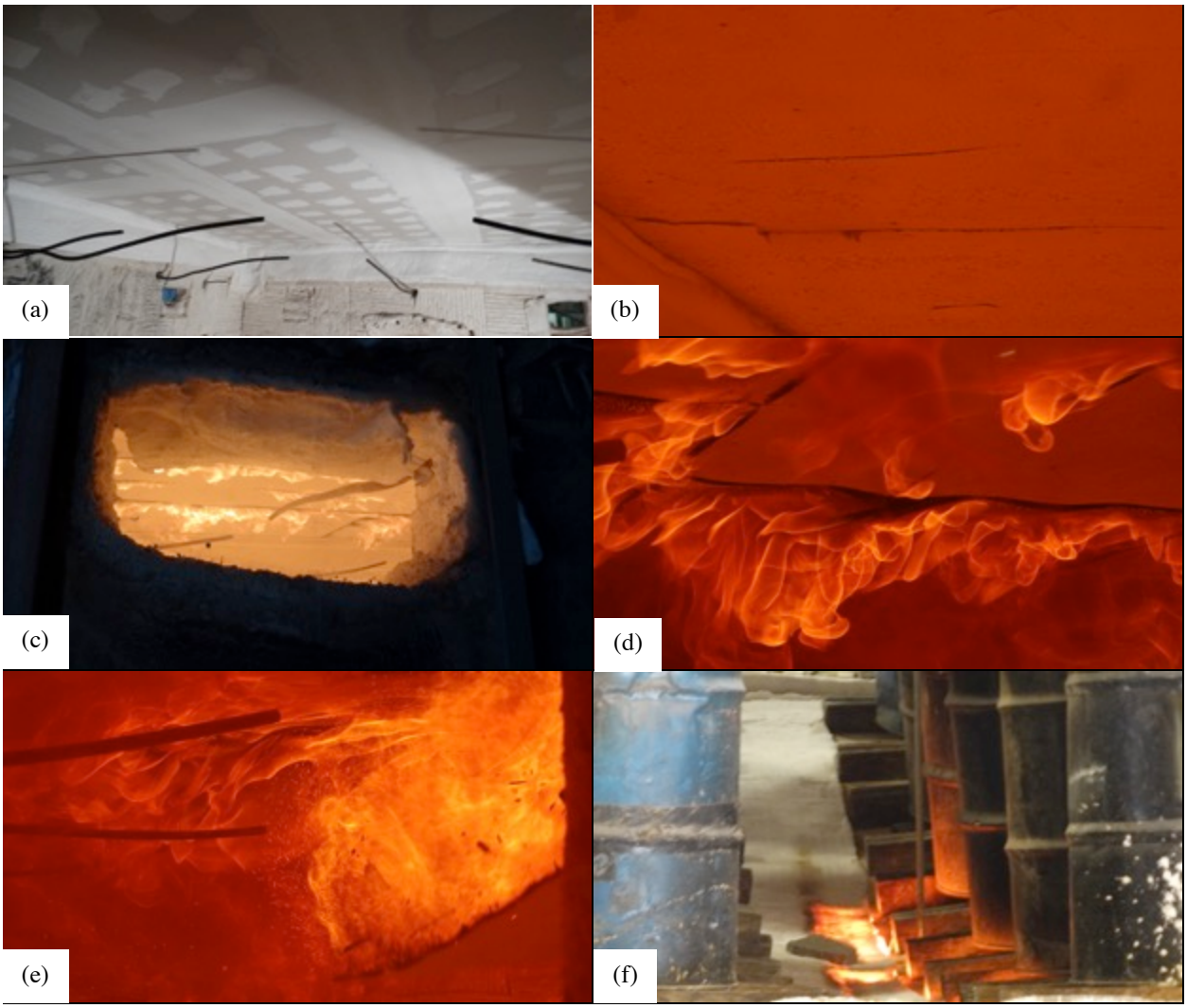

Figure 7. Test 1 floor assembly during test showing (a) before test, (b) field crack – 24 min, (c) flames – 33 min, (d) peeling – 49 min, (e) falling material – 63 min, and (f) glowing at spline joint – 190 min

Temperature Data

The standard time-temperature curve was followed throughout the test period as shown in Figure 8, varying slightly when the assembly was burning intensely and water had to be added to the furnace. There is some variation (0.7%) in the area under the time-temperature curve, below the 5% recommended value for a test beyond 2-hr.

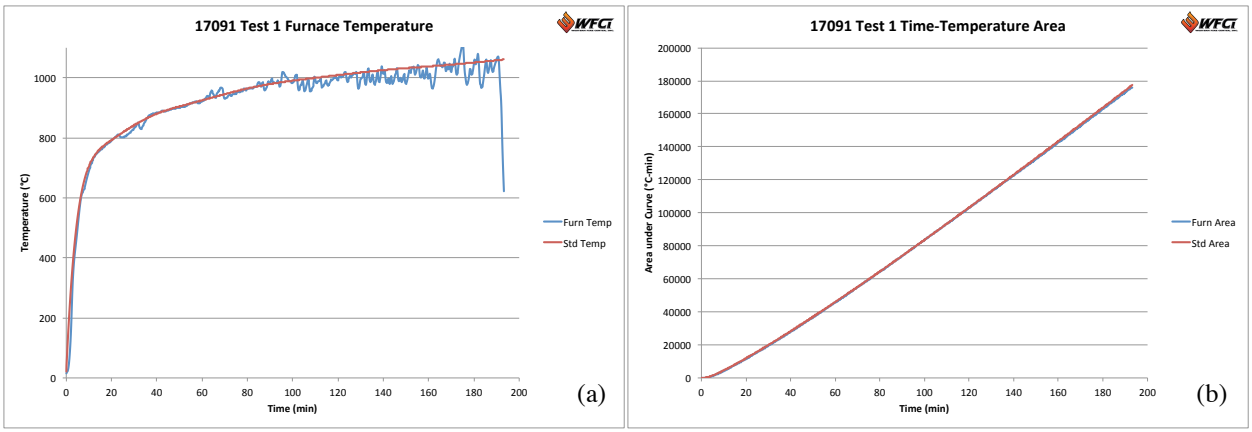

Figure 8. Test 1 (a) furnace temperature and (b) furnace area under the curve compared to the standard curve.

Sample TC_S are shown in Figure 9. The finish layer surpassed the average temperature criteria (139°C + ambient) at 21 m 13 s and continued to increase until the gypsum layer fell off. The single-point unexposed threshold was surpassed (181°C + ambient) at 183 m 0 s at TC_S11.

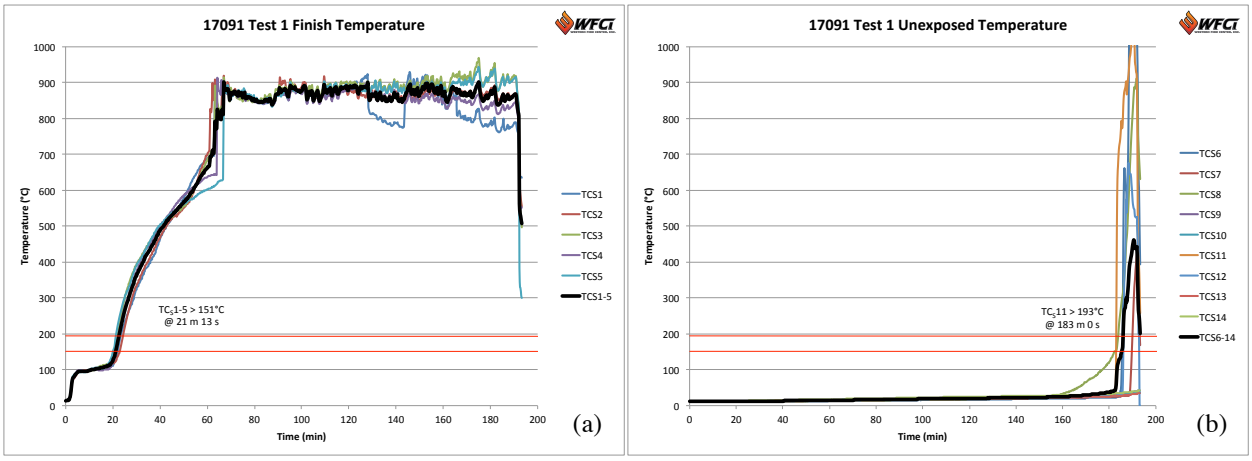

Figure 9. Test 1 sample thermocouples showing (a) finish and (b) unexposed temperature.

Deflection Data

No significant floor deflection, as measured by the LVDT (Figure 10), was observed until 40 min into the test, after which deflection gradually increased until about 125 min into the test, after which the deflection began to increase significantly faster. The deflection surpasses 12" at 189 m 42 s, and the test was terminated shortly thereafter due to imminent collapse.

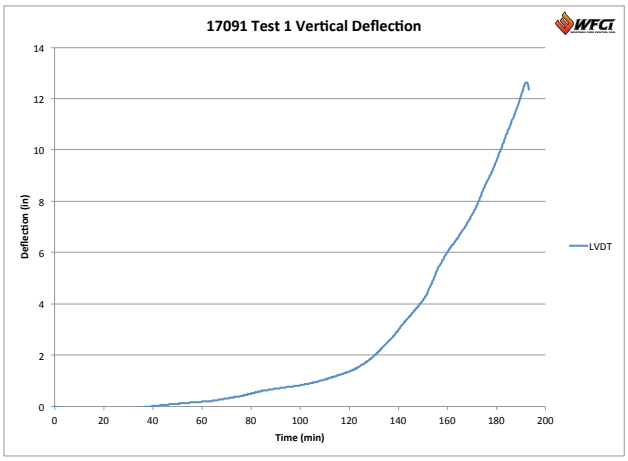

Figure 10. Test 1 deflection measurement near center of assembly.

Discussion

After the furnace was shut off at test termination, the floor was extinguished with water. The post-test examination showed charring into the 4th ply layer with the first three mostly fallen during the test (Figure 11). Charring was more significant at the spline joint.

Figure 11. Test 1 post-test assembly showing (a-b) overall assembly and (c-d) joint.

Test 2: Control

Test Date & Time: 11/1/17, 1:25 PM

Furnace: Large-scale horizontal exposure furnace – full-scale E119

Laboratory Conditions: 15°C, 71% RH

Table 2. Test 2 observations for floor/ceiling test.

Test Time (mm:ss)		**Event**
00:00		Start test – close doors to furnace
01:15		Flames wood face
02:00		Increasing flames – start periodic introduction of water into furnace for temperature control
33:00		Continued flaming – small embers falling
41:00		Larger sections of 1st ply falling
55:30		Continue application of water again
1:17:00		Most of 1st ply fallen
1:25:00		Continued flaming
1:30:00		Approximately 1.7” deflection
1:35:00		2nd ply layer falling
1:56:00		Approximately 4½” deflection
2:04:00		Approximately 5” deflection – popping from assembly
2:10:30		Approximately 7” deflection
2:17:00		Approximately 8¼” deflection
2:19:30		Approximately 8.8” deflection – flames on unexposed side when water applied – localized positive pressure
2:21:18		TC_S8 > 196°C – single-point unexposed rating temperature threshold reached
2:22:30		Approximately 10” deflection
2:25:00		Popping from assembly – approximately 11” deflection
2:25:30		Glowing through Kaowool strip
2:28:30		Approximately 11½” deflection
2:29:20		Sustained flames on unexposed side at joint
2:31:30		Terminate test – deflection beyond 12” – sustained flames along joint

The test was terminated at 151 m 30 s, after the deflection was beyond 12” (149 m 24 s) and failure to the assembly was imminent. Also, sustained flames were observed on the unexposed surface near the joint at 149 m 20 s. Unsustained flames were observed at 140 min, but this was due to localized pressure increase from the water application to the furnace. Thus this assembly fulfilled the requirement of maintaining the applied load without passage of flame for 2 hr 29 m.

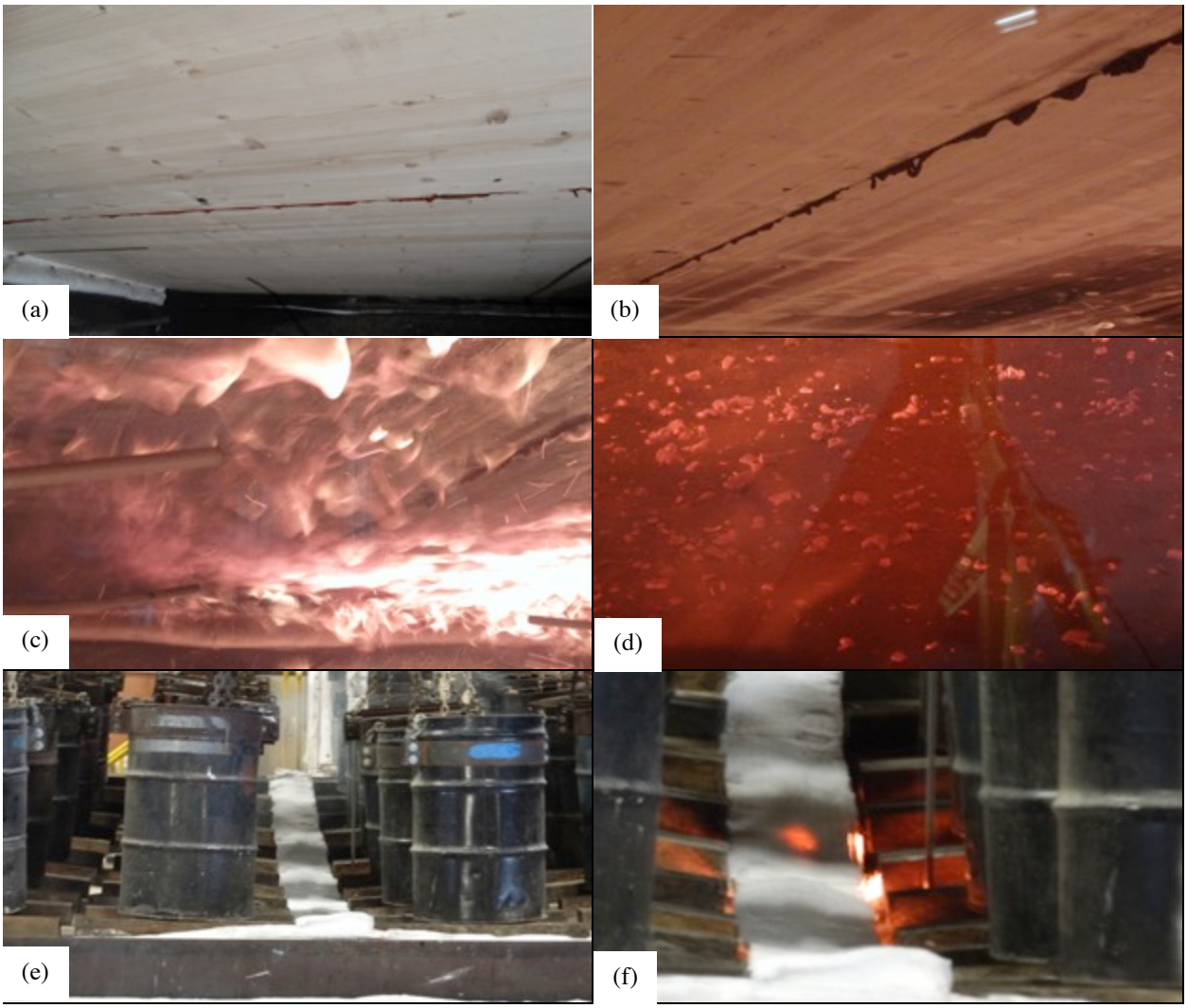

Figure 12. Test 2 floor assembly during test showing (a) before test, (b) darkening – 1 min, (c) flames – 5 min, (d) embers – 35 min, (e) deflection – 138 min, and (f) sustained flames – 149 min.

Temperature Data

The standard time-temperature curve was followed throughout the test period as shown in Figure 13, varying slightly when the assembly was burning intensely and water had to be added to the furnace. There is some variation (1.2%) in the area under the time-temperature curve, below the 5% recommended value for a test beyond 2-hr.

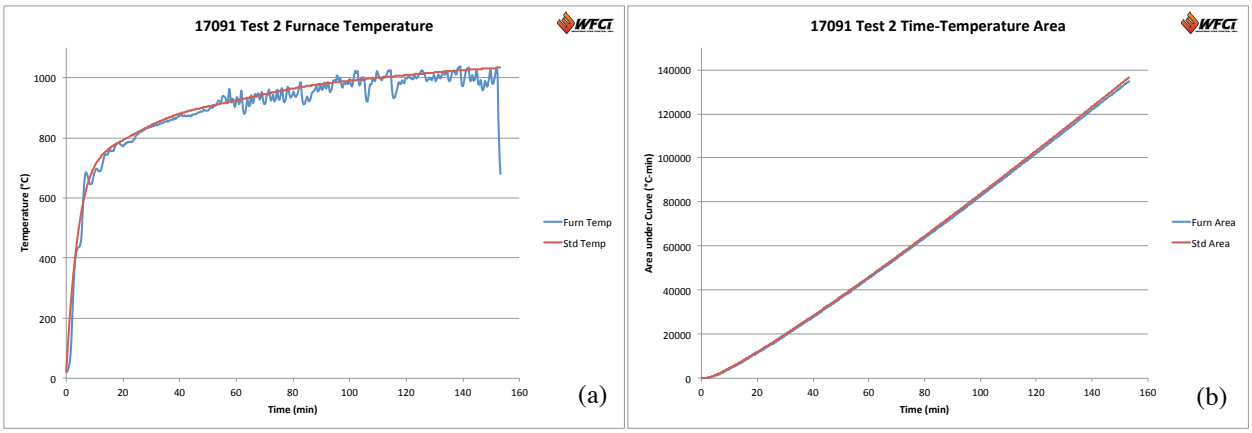

Figure 13. Test 2 (a) furnace temperature and (b) furnace area under the curve compared to the standard curve.

Sample TC_S are shown in Figure 14. The single-point unexposed threshold was surpassed (181°C + ambient) at 141 m 18 s at TC_S8.

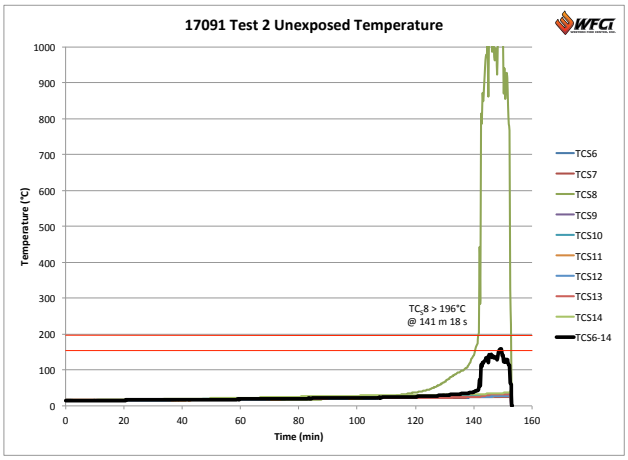

Figure 14. Test 2 sample thermocouples showing unexposed temperature.

Deflection Data

No significant floor deflection, as measured by the LVDT (Figure 15), was observed until 5 min into the test, after which deflection gradually increased until about 100 min into the test, after which the deflection began to increase significantly faster. The deflection surpassed 12" at 149 m 24 s, and the test was terminated shortly thereafter due to imminent collapse.

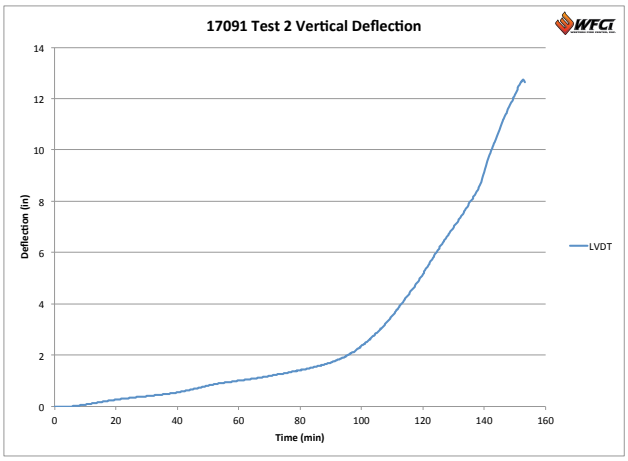

Figure 15. Test 2 deflection measurement near center of assembly.

Discussion

After the furnace was shut off at test termination, the floor was extinguished with water. The post-test examination showed charring into the 4th ply layer with the first three mostly fallen during the test (Figure 16). Charring was more significant at the spline joint.

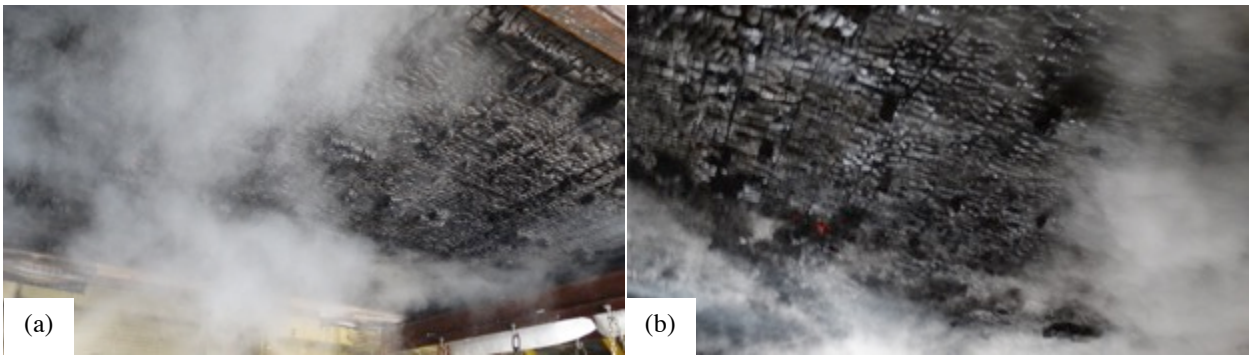

Figure 16. Test 2 post-test assembly showing (a-b) overall assembly.

Test 3: Three Layers Gypsum

Test Date & Time: 11/3/17, 8:05 AM

Furnace: Large-scale horizontal exposure furnace – full-scale E119

Laboratory Conditions: 14°C, 73% RH

Table 3. Test 3 observations for floor/ceiling test.

Test Time (mm:ss)		**Event**
00:00		Start test – close doors to furnace
02:20		Charred gypsum paper
11:30		Falling sections of compound at butt joint
20:48		$TC_S18\text{-}20 > 153°C$ – average middle/face threshold
37:00		Cracks in gypsum

56:00		Approximately ¼" to ⅜" gap in face layer joint
1:01:39		TC_S15-17 > 153°C – average base/middle threshold
1:33:00		Gypsum fallen on west side of assembly
1:38:30		Flames from paper at west side near fallen gypsum – flames out at 1:40:00
1:49:00		Most of face layer fallen – cracks in middle layer
1:50:06		TC_S4 > 195°C – single-point finish rating temperature threshold reached
1:58:00		Flames from middle layer joints
2:07:00		Falling sections of middle layer on west side
2:13:00		More fallen sections of middle layer
2:25:00		Increasing flames
2:26:30		Joints opening – base layer peeling away
2:48:00		Start periodic introduction of water into furnace for temperature control
3:50:00		Approximately 4.1" deflection – no visibility in furnace
3:59:00		Approximately 4½" deflection
4:05:00		Approximately 5½" deflection
4:17:00		Approximately 7" deflection
4:23:30		Approximately 8" deflection
4:26:00		Flames on unexposed side when water applied – localized positive pressure
4:27:30		Approximately 9" deflection
4:30:30		Approximately 10" deflection
4:32:50		Popping from assembly
4:34:00		Approximately 11" deflection
4:36:00		Sustained flaming on unexposed surface
4:36:40		Terminate test – large popping from assembly – deflection beyond 12" – sustained flames on unexposed surface – assembly collapsed during extinguishment

The test was terminated at 276 m 40 s, after the deflection was beyond 12" (276 m 31 s) and failure to the assembly was imminent. The assembly collapsed during extinguishment. Also, sustained flames were observed on the unexposed surface near the joint at 276 m 0 s. Unsustained flames were observed at 266 min, but this was due to localized pressure increase from the water application to the furnace. Thus this assembly fulfilled the requirement of maintaining the applied load without passage of flame for 4 hr 36 m.

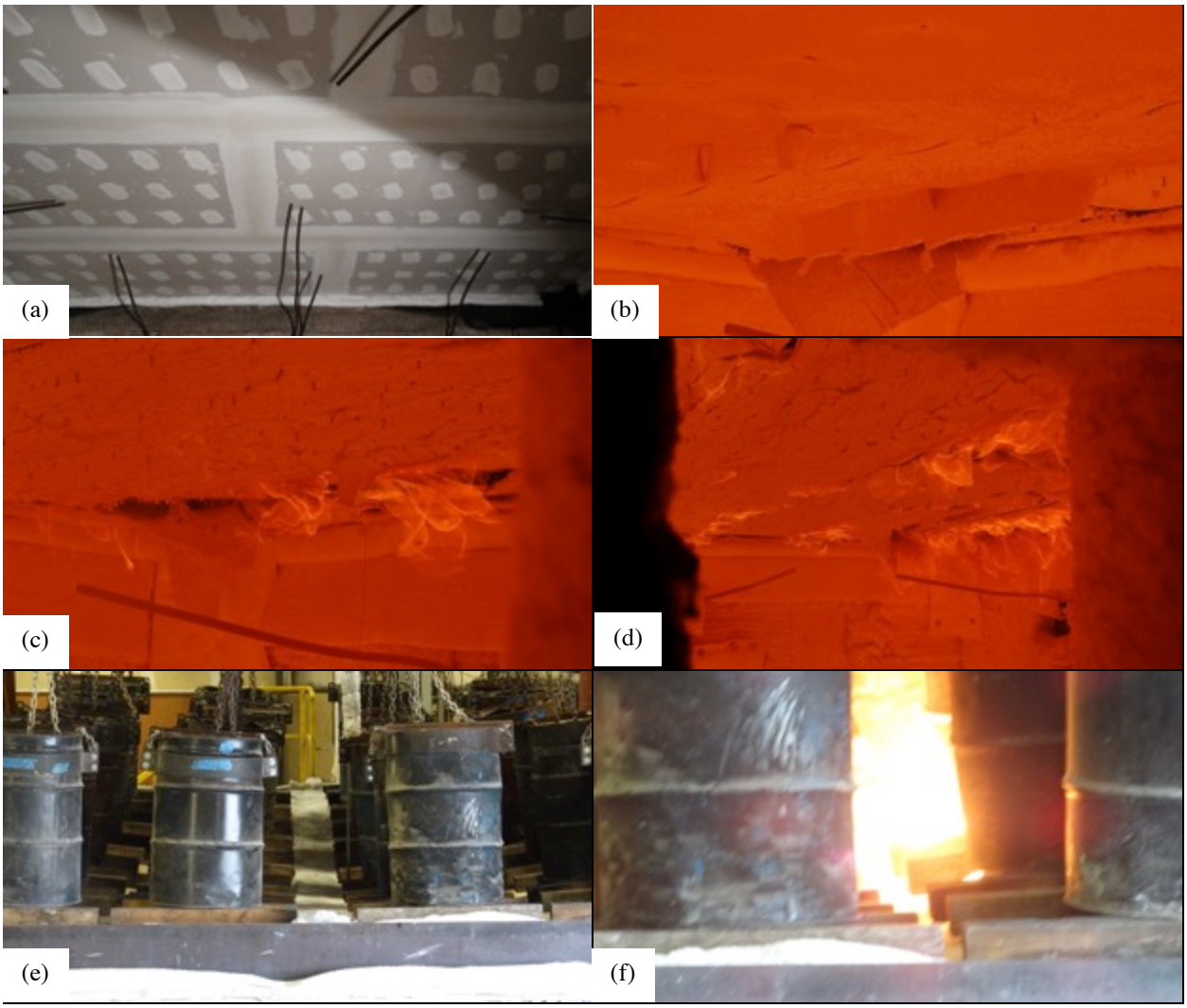

Figure 17. Test 3 floor assembly during test showing (a) before test, (b) fallen face layer – 98, (c) fallen middle layer – 128 min, (d) increasing flames – 134 min, (e) bowed floor – 273 min, and (f) flames – 277 min.

Temperature Data

The standard time-temperature curve was followed throughout the test period as shown in Figure 18, varying slightly when the assembly was burning intensely and water had to be added to the furnace. There is some variation (0.1%) in the area under the time-temperature curve, below the 5% recommended value for a test beyond 2-hr.

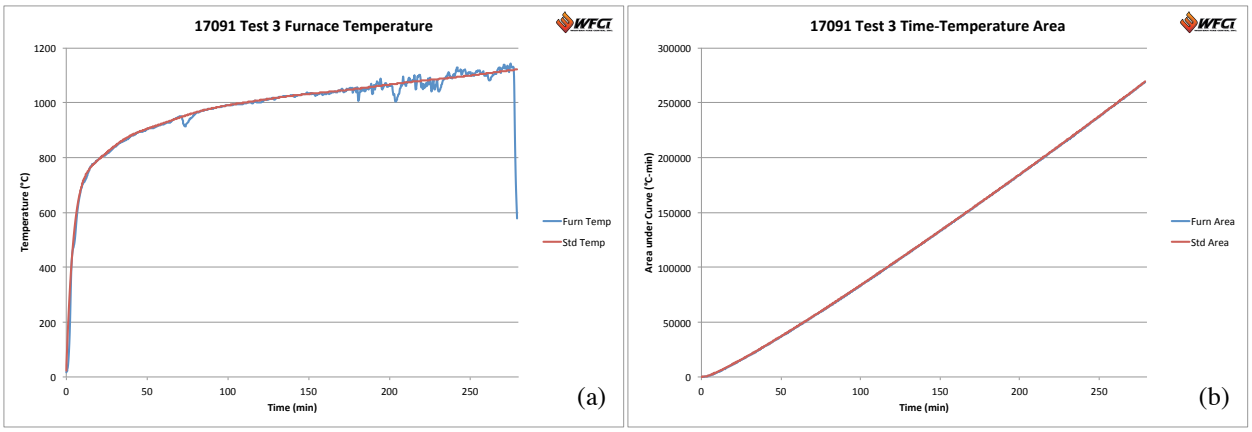

Figure 18. Test 3 (a) furnace temperature and (b) furnace area under the curve compared to the standard curve.

Sample TC_S are shown in Figure 19. The finish layer surpassed the single-point temperature criteria (181°C + ambient, TC_S4) at 110 m 6 s and continued to increase until the base layer gypsum fell off. The unexposed threshold did not surpass the average or single-point thresholds (139°C + ambient, 181°C + ambient), but had a final average value of 63°C. The average interface layers surpassed their respective thresholds at 20 m 48 s (middle/face) and 61 m 39 s (base/middle).

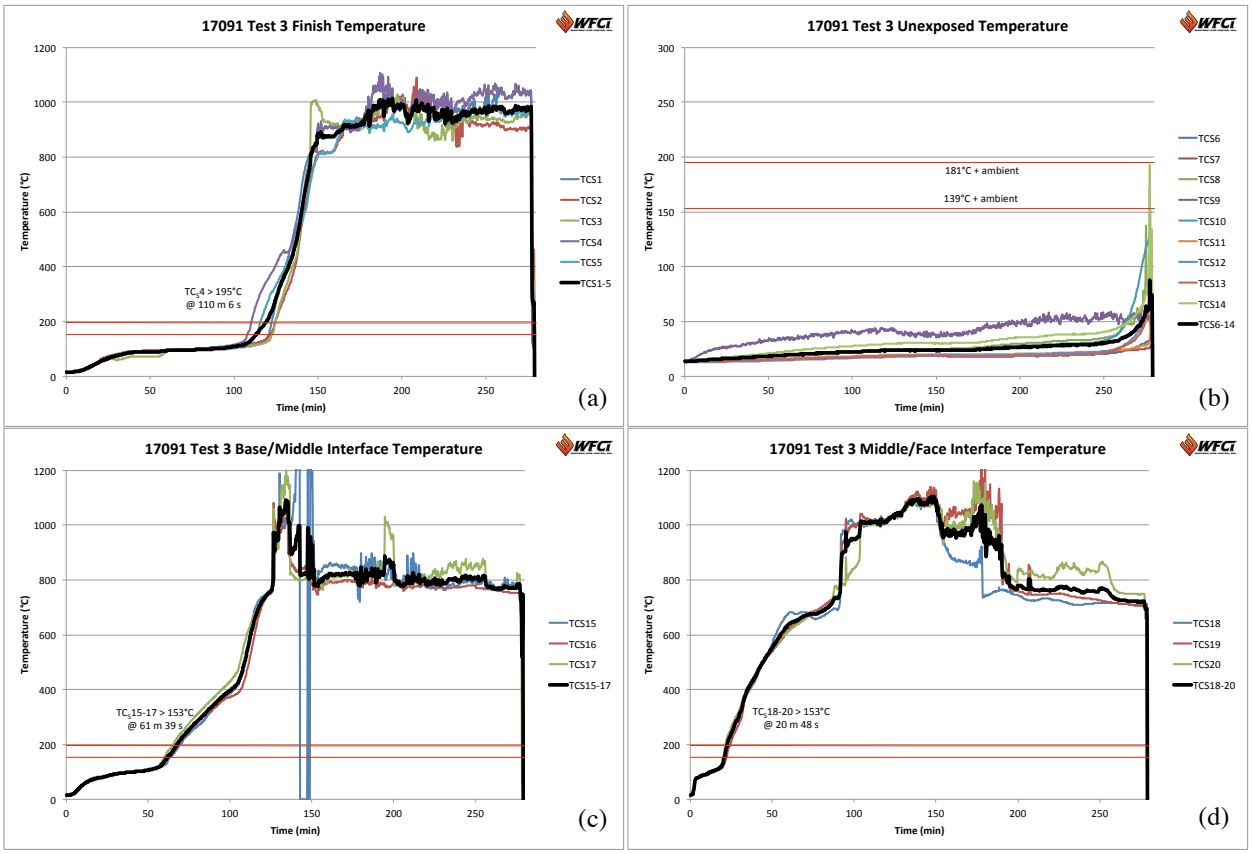

Figure 19. Test 3 sample thermocouples showing (a) finish, (b) unexposed, (c) base/middle, and (d) middle/face temperatures.

Deflection Data

No significant floor deflection, as measured by the LVDT (Figure 20), was observed until 125 min into the test, after which deflection gradually increased until about 210 min into the test, after which the deflection began to increase significantly faster. The deflection surpassed 12" at 276 m 31 s, and the test was terminated shortly thereafter due to imminent collapse. The assembly did indeed collapse during extinguishment at 278 m 9 s.

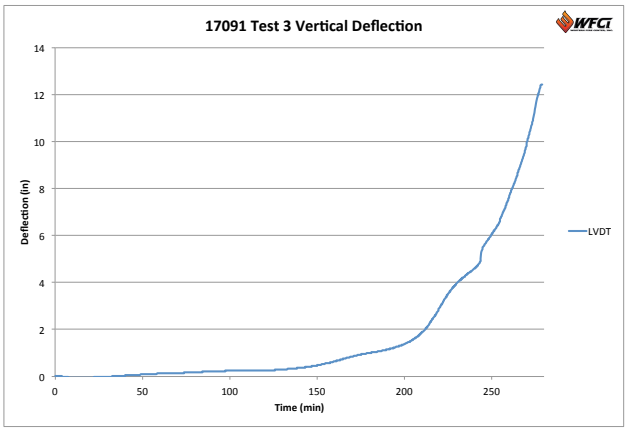

Figure 20. Test 3 deflection measurement near center of assembly.

Discussion

After the furnace was shut off at test termination, the floor was extinguished with water during which the west side of the assembly collapsed. The post-test examination showed some charring into the 4nd and 5th ply layers with the first three mostly fallen during the test (Figure 21). Charring was more significant at the spline joint.

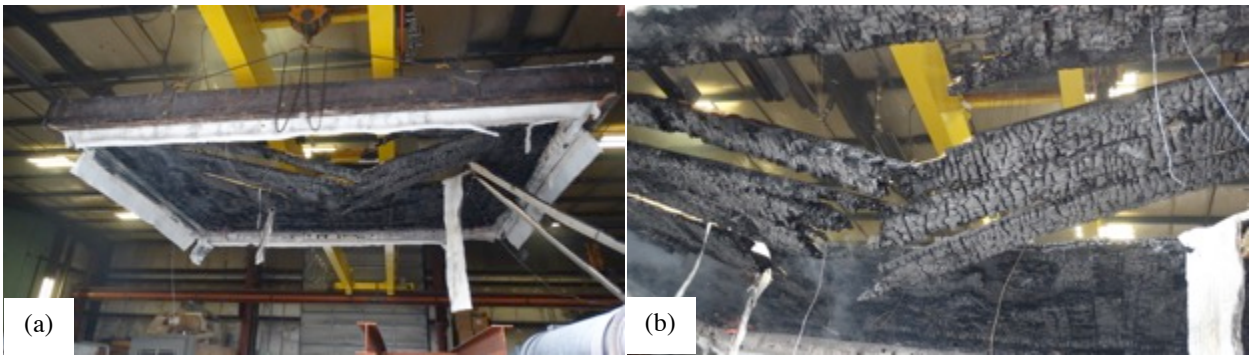

Figure 21. Test 3 post-test assembly showing (a) overall assembly and (b) fractured panel.

CONCLUSION

Three CLT floor/ceiling assemblies with various layers of gypsum as described above were tested under a standard time-temperature exposure according to ASTM E119, *Standard Test Methods for Fire Tests of Building Construction and Materials*. The floor/ceiling assemblies were carried to near complete structural failure, or beyond 12" deflection all cases. A summary of each test with failure criteria is shown in Table 4.

Table 4. Failure summary from E119 tests, rounded to nearest integral minute.

Test	Gypsum Layers	Finish (min)	Unexposed (min)	Unsustained Flaming (min)	Sustained Flaming (min)	Structural Failure* (min)	Test End (min)
1	One	21	183	185	190	190	191
2	None	N/A	141	140	149	149	152
3	Three	110	> 277	266	276	277	277
*Defined when deflection went beyond 12". Collapse imminent.							

SIGNATURES

Reviewed and Approved by,

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Testing performed by,

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Technical Director

The test specimen identification is as provided by the client and WFCi accepts no responsibilities for any inaccuracies therein. WFCi did not select the specimen and has not verified the composition, manufacturing techniques or quality assurance procedures.

Version	Date Issued	Document Number	Changes
Original	November 8, 2017	17091	Original report
Revision 1	November 28, 2017	17091r1	Clarification for CLT panel tests for comparative purposes by determining imminent structural failure when the mid-point deflection of the assembly is beyond 12” rather than using the standard temperature and flame criteria. Additionally minor edits to clarify text phrases.

Appendix A – Additional Figures

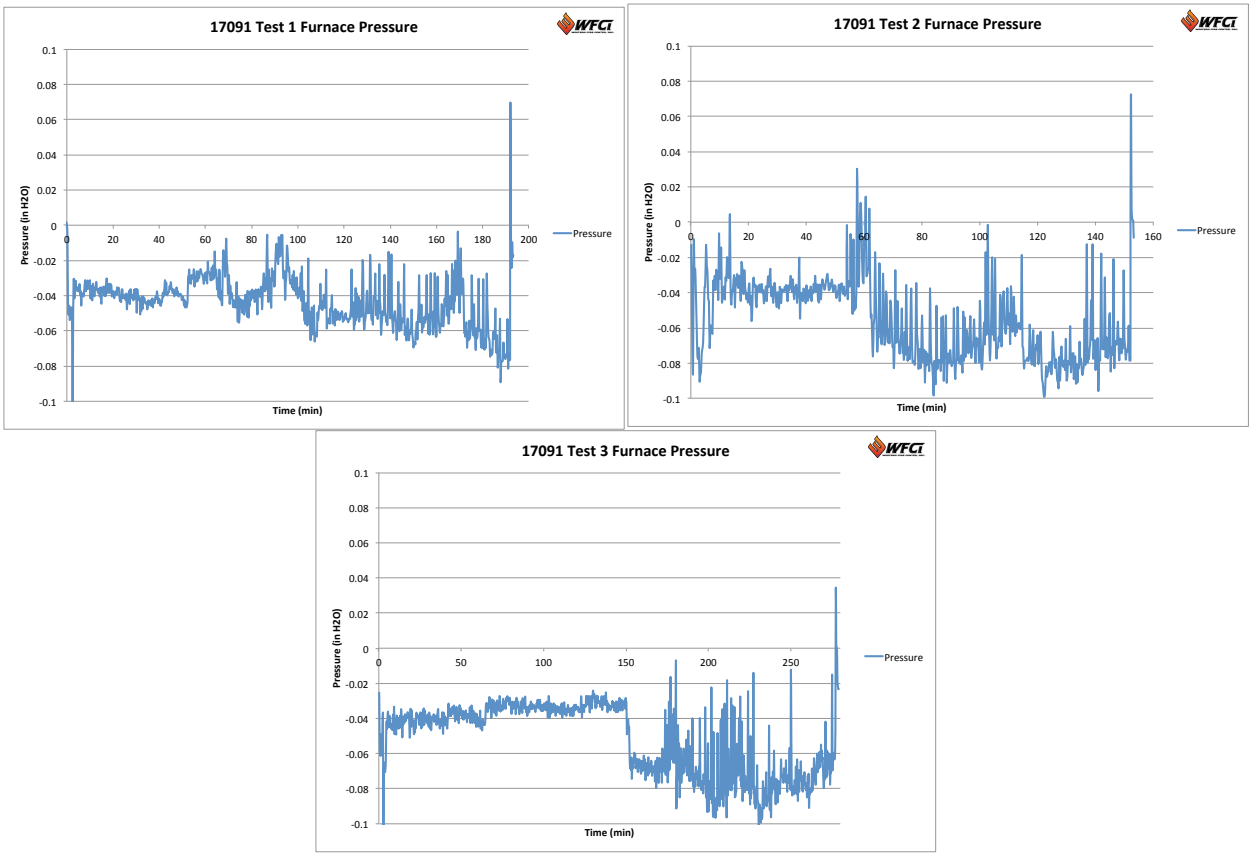

Figure A 1. Furnace pressure for (a) Test 1, (b) Test 2, and (c) Test 3.

Figure A 2. Construction showing (a) Test 1 joint, (b) firestop, (c) construction adhesive, (d) spline screws, (e-f) gypsum, (f) 3” screws, (g) 1⅝” screws, (h) 2¼” screws, and (i) underside CLT.

Figure A 3. Additional sequential photos for Test 1.

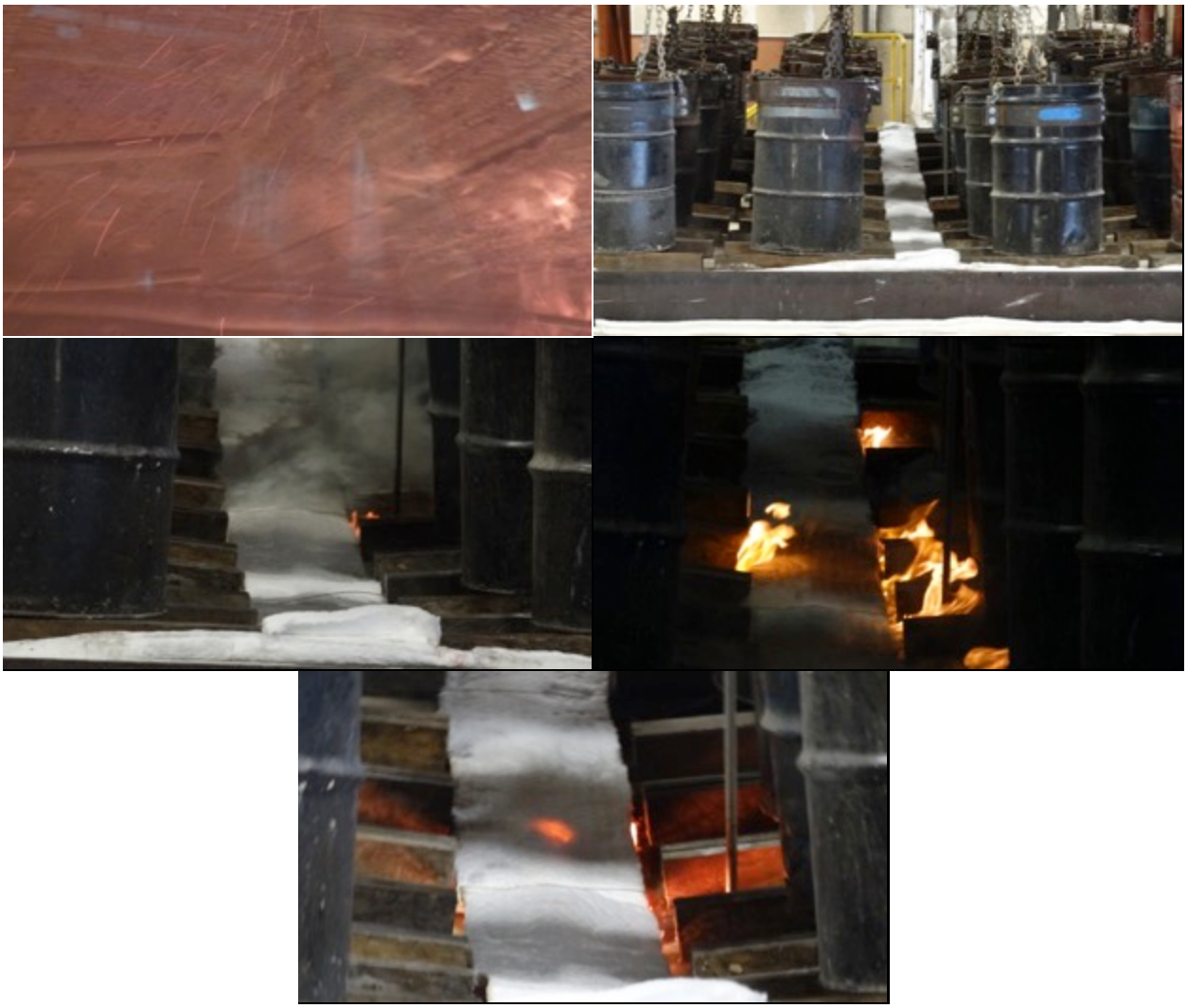

Figure A 4. Additional sequential photos for Test 2.

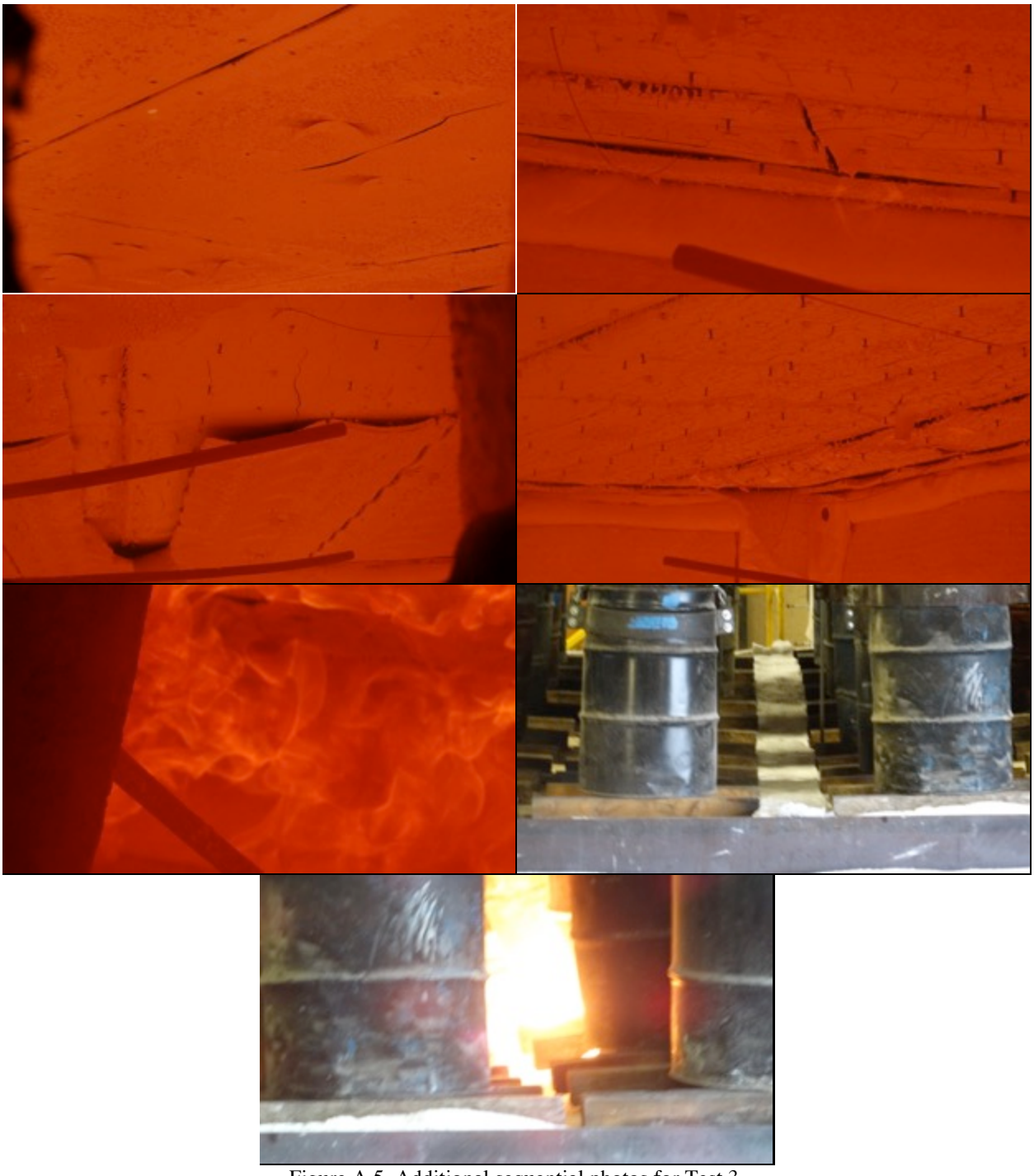

Figure A 5. Additional sequential photos for Test 3.